Time lapse velocity monitoring with different microseismic sources

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Coda waves
Coda waves
Coda waves
Repeatability

↑

Source location
Source mechanism
Source location shift

\[ D = \lambda_d \]
Source mechanism

$\phi = 90^\circ, \lambda = 0^\circ, \delta = 0^\circ$

$\phi = 70^\circ, \lambda = 20^\circ, \delta = 20^\circ$
Source mechanism

![Diagram showing early and late coda with normalized amplitude versus time.](image-url)
Motivation

- What microseismic events can we use for monitoring velocity changes?
- How does the repeatability of events influence the accuracy of the estimated velocity change?
The unperturbed seismic signal $U(t)$

$$U(t) = A \sum_{T} U^{(T)}(t)$$
Perturbed seismic signal $\hat{U}(t)$

$$\hat{U}(t) = \hat{A} \sum_{T} (1 + r^{(T)}) U^{(T)}(t - t_{p}^{(T)})$$
Traveltime perturbation \( t_{p}^{(T)} \) depends on
- shift in source location \( D \)
- subsurface velocity change \( \delta V \)

Amplitude perturbation \( r^{(T)} \) depends on
- change in source mechanism \( (\Delta \phi, \Delta \lambda, \Delta \delta) \)
Statistics of time perturbation

Average time perturbation $\langle t_p \rangle$

$$\langle t_p \rangle = -\left\langle \frac{\delta V}{V_o} \right\rangle t$$
Statistics of time perturbation

Average time perturbation \( \langle t_p \rangle \)

\[
\langle t_p \rangle = -\langle \frac{\delta V}{V_o} \rangle t
\]

Independent of \( D \) and \( \langle r \rangle \)
Statistics of time perturbation

Variance of the time perturbation

\[ \sigma_t^2 = \langle t_p^2 \rangle - \langle t_p \rangle^2 \approx \frac{D^2}{3V_0^2} \]
Statistics of amplitude perturbation

Average amplitude perturbation $\langle r \rangle$

$$\langle r \rangle = -\frac{1}{2}(4\Delta \phi^2 + \Delta \lambda^2 + \Delta \delta^2)$$

(Robinson et al., 2007)
Numerical validation
Model parameters

\[ \epsilon = \left\langle \frac{\delta V}{V_0} \right\rangle \% \]

\[ \langle r \rangle (\Delta \phi (\circ), \Delta \lambda (\circ), \Delta \delta (\circ)) \]

\[ D/\lambda_d \]
Scattered wave

Normalized amplitude

Time (s)
Scattered wave
Data processing

Stretching algorithm

$$\hat{U}(t(1 - \epsilon)) \rightarrow U(t)$$

where,

$$\epsilon = \left\langle \frac{\delta V}{V_0} \right\rangle$$

(Hadziioannou et al., 2009)
Optimization

\[ R(\epsilon) = ||\hat{U}(t(1 - \epsilon)) - U(t)||_2 \]
Estimated velocity change

![Graph showing estimated velocity change with Legend: 0.4%, 0.3%, 0.2%, and 0.1%]

- Receiver number
- Relative velocity change (%)
- 0.1%
- 0.2%
- 0.3%
- 0.4%
Estimated velocity change: source location shift

Relative velocity change (%) vs Receiver number for different values of $D/\lambda_d$. The graph shows fluctuations in relative velocity change with varying receiver numbers.
Maximum source location shift

\[
\frac{D}{\lambda_d} < \sqrt{2} \left| \left\langle \frac{\delta V}{V_0} \right\rangle \right| f_d t
\]
Maximum source location shift

\[ \frac{D}{\lambda_d} < 0.35 \]
Estimated velocity change: source mechanism
Maximum source mechanism

\[ \Delta \alpha = \Delta \varphi = \Delta \lambda = \Delta \delta \]

Relative velocity change (%)

Source radiation perturbation (\(\Delta \alpha \) [\(^{\circ}\)])
Maximum source mechanism

\[ \Delta \alpha = \Delta \varphi = \Delta \lambda = \Delta \delta \]

Source radiation perturbation (\(\Delta \alpha [^\circ]\))

Relative velocity change (%)

- Station SW
- Station SE
- Station NE
- Station NW

0.01%
\( \langle \delta V / V_0 \rangle \) can be estimated from microseismic coda when:

- \( \frac{D}{\lambda_d} < \sqrt{2} \left| \langle \frac{\delta V}{V_0} \rangle \right| f_d t \)
- \( \Delta \alpha \leq 28^\circ \rightarrow \leq 0.01\% \langle \delta V / V_0 \rangle \) error
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